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ABSTRACT

Presented is a study of eighth-grade students' academic problem-solving ability based on their knowledge structures, or their information stored in semantic or long-term memory. The authors describe a technique that they developed to probe knowledge structures with an extension of the card-sort method. The method, known as the Concept Structure Analysis Technique (ConSAT), allows for students to produce graphic structural representations directly, which eliminates the need for statistical procedures to transform data from raw form to graphic form. The advantages of the technique are: (1) having the ability to search for relations between concepts; (2) the ability to analyze structural changes of individuals resulting from instruction; and (3) the ability to search for the integration of more than one kind of structure. (Author/SA)

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THE INFLUENCE OF SCIENCE KNOWLEDGE STRUCTURES ON CHILDREN'S SUCCESS IN SOLVING ACADEMIC PROBLEMS

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THE INFLUENCE OF SCIENCE KNOWLEDGE STRUCTURES ON CHILDREN'S SUCCESS IN SOLVING ACADEMIC PROBLEMS

Knowledge structures, the information-processing term for organized networks of information stored in semantic or long-term memory, have received much attention in recent years both from researchers who study the structure of human memory (e.g., Bower, 1975; Kintsch, 1974) and from those who explore the role of knowledge structures in the learning of academic subject matter (e.g., Greeno, 1978; Shavelson and Stanton, 1975).

In the case of the former group, current studies of how knowledge is represented in semantic memory include such work as the study of how knowledge of geometry is represented (Greeno, 1977), how stories are represented (Rumelhart, 1975), and how various types of simple and complex problems are represented and solved (Newell and Simon, 1972; Greeno, 1978). Drawing on this growing body of theory and empirical work, researchers in the latter group have attempted to develop measures of knowledge structures, to trace changes in structure as a result of instruction, and to explore the relationship between knowledge structures and problem solving.

In a vein similar to the second of these research thrusts, the research we report here calls upon information-processing psychology for notions that may suggest possible fruitful relationships to explore between knowledge structures and issues of instructional import. In particular, we have investigated the relationship between students' structuring ability and their success in solving verbal academic

problems.

The link we perceive between knowledge structures and success in solving verbal academic problems is suggested in the speculations of Greeno (1978) on the nature of knowledge structures and cognitive processes involved in solving problems. Greeno (1973) has proposed that in semantic memory two kind of knowledge are stored, propositional and algorithmic. Propositional knowledge refers to concepts and the relations between them, structures sometimes thought of as concept networks. Algorithmic knowledge "is in the form of operations or rules" and "translates readily into action" (p. 114). A parallel distinction is made by Sacerdoti (1977) who uses the terms declarative (for propositional) and procedural (for algorithmic) knowledge, and both conceptualizations touch base with our present research since they point to two possible major components of problem-solving performance.

In a more recent publication, Greeno (1978) describes a typology of problem-solving skills that contains three major categories: problems of inducing structure, of transformation, and of arrangement. Of particular importance to our work is his discussion of problems of inducing structure, a prototypical example being verbal analogies of the sort, _A is to B as C is to D_. Greeno proposes that the processes in solving analogies and similar induction problems are closely analogous to the processes involved in understanding language (_e.g._, text). In each case it is postulated that an individual must identify relations between components (concepts) and then combine them into integrated patterns. Although he does not discuss these processes in terms of his propositional/algorithmic distinction, we believe it is accurate to

interpret his supposition as a claim that in both cases the individual must construct a propositional knowledge structure. Greeno further proposes that solving analogies is more difficult than understanding a sentence, since the relations must be induced in the case of analogies problems.

With respect to research concerned with relating measures of knowledge structures and problem solving, Greeno's formulation suggests that individuals who are better structurers of knowledge should be more successful solvers of analogies and similar types of problems. What is required to study this implication is a technique that both adequately represents knowledge structures in school subject matters and monitors changes in structures as a result of instruction. Also needed is a procedure for reliably distinguishing between highly competent and less competent structurers.

The most popular techniques investigators have used to probe knowledge structures continue to be variations of word association and similarity-rating tasks (e.g., Shavelson, 1974; Preece, 1976a). Graph-tree construction and card-sort tasks (e.g., Shavelson, 1974), more recent additions, can be classed as similarity rating procedures. The essential characteristic of all these tasks is that subjects link concepts, usually words. Instructions may direct subjects to generate words upon presentation of a "stimulus" term or to relate terms on the basis of their similarity. Only in the graph-tree construction procedure do subjects connect large numbers of concepts in one hierarchical structure. Card-sort task instructions generally ask subjects to place similar terms into groups.

Transforming the raw data into a graphic representation of structure has often been the aim of researchers, who have employed various techniques including multidimensional scaling (e.g., Shavelson, 1974; Preece, 1976a), hierarchical clustering, and Waern's graphing procedure (see Preece, 1976a). These statistical procedures, which yield group structures, have been the subject of criticism for the assumptions they make about the "underlying" structure of knowledge, for the reasonableness of statistical assumptions that must be satisfied, and for their reliance on "eyeballing" the visual representations as the last step of the analysis (see Eignor, 1978).

The technique we have developed to probe knowledge structures and analyze the representations is an extension of the card-sort method described by Shavelson and Stanton (1975) in their validation study of three methodologies for representing knowledge structures. However, our approach, called the Concept Structure Analysis Technique (ConSAT), differs in several respects from the card-sort procedure and subsequent statistical analyses. With the ConSAT, students produce graphic structural representations directly, thus eliminating the necessity of using statistical procedures to transform raw data into a graphic form. Also, structures of individuals are represented, relations between concepts as well as associations between them are probed, and the integration of more than one kind of structure can be represented and analyzed. Student structures can then be compared with a "standard", students who are competent structurers can be identified, and the relationship between the ability to structure and success in solving problems of inducing structure can be investigated.

Method

Students

The study was carried out in a sectarian elementary school located in a large city. The school's approximately 400 students in grades K through 8 come from middle class homes in the immediate neighborhood. The science teacher selected 30 students, 17 female and 13 male, from the eighth grade classes to participate in the study. All students were familiar with the mechanics of using the self-instructional materials used in the study, since they had previously studied science units in the *Individualized Science* program from which the instructional materials were drawn. None of the students had previously received instruction in geology.

Materials

The instructional materials used in this research, developed by the authors of this paper, deal with the subject of minerals and rocks, and consist of a segment of the field-testing version of the Lyell Unit of the *Individualized Science* program (Champagne and Klopfer, 1974, 1972-1975). The Lyell Unit includes aspects of descriptive, historical, and physical geology. The Invitaton to Explore (ITE) Minerals and Rocks is primarily descriptive geology. The student's booklet for the ITE is 67 typewritten pages long, and consists of reading text, manipulative activities, and student self-administered progress tests. On the average, a student completes the ITE in three to four weeks with five 45-minute periods per week.

The ITE Minerals and Rocks was designed to incorporate structural features of the content of descriptive geology. The structural relations include hierarchical class-inclusion, transformational, and definitional relations. The ITE is organized, in part, around the definition of a mineral and the taxonomic classificaton of rocks. The two most important structural relations, one hierarchical and the other transformational, are the classification of rocks on the basis of how they form and the rock cycle through which each of three kinds of rock--igneous, metamorphic, sedimentary--can be transformed into either of the other kinds.

The ITE begins by setting a structural context for the student. The content structure is described in the text and is represented visually with a drawing that illustrates both the hierarchical relationships among major concepts and examples of the concepts. The introductory narrative summarizes these relations, which are elaborated on throughout the text of the ITE. Transformational relations are another major structural feature represented in the text of the ITE.

Procedure

The diagram below indicates the sequence of steps in the study.

```
 Concept                                                       Concept
structuring---->Pretest---->Instruction---->Posttest---->structuring
  task                                                          task
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First, we administered pre-instructional concept structuring tasks. These tasks probed for structural knowledge about the concepts of descriptive geology in our instructional materials. The students then took a pretest on science content contained in the materials. Third, the students received four weeks of instruction using the ITE Minerals and Rocks. Instruction was followed by a posttest, almost identical with the pretest, and concept structuring tasks, which were the same as the ones administered before instruction. The study was carried out over a period of six weeks, with one week before and after instruction for administering the concept structuring tasks.

The pre- and post-tests were divided into three parts: a multiple-choice item test covering the science content of the ITE; an analogies items test using key terms used in the instructional materials [e.g., seashell is to ______ as diamond is to carbon: (1)natural, (2)calcium carbonate [correct choice], (3)molecule, (4)atom] and a set-membership items test where each item contains a set of four terms, one of which the student had to identify as not belonging to the set (e.g., Cross out the word that does not belong with the other three: lava limestone sandstone shale). The pre- and post-tests differed only in Part I, which contained 45 responses on the pre-test and additional responses on the post-test. These tests were administered by the classroom teacher.

The concept structuring tasks were administered in three parts. The first part probed students' knowledge structures of prerequisite science concepts, i.e., concepts the designers presumed students comprehended and which were necessary for comprehension of the science

content in the ITE Minerals and Rocks. The second part probed structural knowledge of minerals, and the third part concerned structural knowledge of rocks. For each task, we used a different set of cards on which the concepts were printed.

The concept structuring tasks were individually administered in the following manner. Each student was told the purpose of the study and was then led through a practice task that consisted of cards containing familiar anatomical terms. The terms included in each set are listed in Figure 1 under their respective headings: practice task, ATOM task, MINERAL task, and ROCK task. For both the practice task and each succeeding task, the student was shown the set of cards and asked if she recognized each term in the set. Then, using the recognized terms, the student was told that the object of the task was to arrange the cards in a way that would show "how you think about the words." The arrangement was laid out on a large piece of paper (28 x 41 cm) and the cards, which had an adhesive on their reverse sides, were pressed into place. The student was then asked to explain why he or she arranged the words in this particular way. The responses were recorded by drawing lines on the paper between cards designated by the student and writing in the relations between words as described by the student. The procedure for administering the concept structuring task was the same before and after instruction, except that it was unnecessary to conduct the practice task on the post-instructional administration.

INSERT FIGURE 1 ABOUT HERE

Analysis of Knowledge Structure Representations

The method we devised for analyzing the data depends on ascertaining the degree of correspondence between students' structures and a standard structure. For this study, congruence between student knowledge structures and content structure is determined by comparing certain characteristics of the representations of student knowledge structures with those of a theoretically derived standard structure. In deriving the standard structure, we assumed (a) that the scientific writings of experts in a field are representations of the content structure of that discipline, and (b) that in some way or ways, the structure of the discipline is congruent with knowledge structures of experts, since the way experts write about a subject must reflect to some degree how they think about the subject (i.e., writing reflects knowledge structure). Thus, to obtain a representation of the content structure of the discipline two alternatives are available: (1) to empirically obtain representations of knowledge structures of a number of people knowledgeable in a field and identify characteristics common to them, or (2) to consult the writings of experts and derive the structures of the discipline based on the above assumptions. An example pertinent to our study is the representation of the structure of the discipline of geology in materials written by experts in the field. Geologists tend to write (and think) about rocks in a way that shows that rocks are classified on the basis of a transformational cycle.

When a geologist (or any scientist) classifies objects in accordance with the prevailing ideas of the science discipline, he or she is doing much more than sorting things into groups. The particular scheme of classification that is commonly used by the practitioners of a science at a given time reflects the principal theory or beliefs concerning the science's domain at that time. As a science evolves and its theories change, the changes are reflected in a revised classification scheme for rocks. When the knowledge structure of an expert displays three principal groups--igneous, metamorphic, sedimentary-- it displays at the same time much of the current theory, i.e., the conceptual structure, of physical geology. Other possible schemes for classification could be based, for example, on the physical characteristics of the samples or on their chemical composition as well as more conceptually on the way in which they were formed. Any one of these schemes could be equally valid if it suited the particular purpose for classifying the samples. The knowledge structure as derived from scientific writings about geology are important in our analysis of student knowledge structures.

The degree of correspondence between student and standard structures is ascertained by assessing the extent to which certain crucial attributes of the standard structure are present in the student structure. First, from a careful analysis of the standard structure, we prepare qualitative descriptions of the crucial attributes it exhibits. Then we search the student structure for the attributes and, depending on whether they are present or absent, we assign the student structure to one of several structure classes. These structure classes, which are defined chiefly on the basis of the crucial attributes of the standard structure, are arranged in order of increasing complexity. In the

lowest structure class, the organizing attribute is simply some graphemic property common to the words themselves, for example, the common "-ite" ending for names of minerals. In the more complex classes, the words are treated as concepts, and it is the concepts which are structured according to various attributes that relate them. A different series of structure classes has to be defined, of course, for every set of concepts presented in a concept structuring task.

For both the ROCK and MINERAL concepts which were used in our structuring tasks, we carried out analyses of the knowledge structure representations as just outlined. A detailed description of how we analyzed the ROCK concepts and defined the ROCK structure classes is given in Champagne et al (Note 1). From that analysis, we reproduce here the standard structure for the ROCK concepts (Figure 2) and the chart summarizing the ROCK structure classes (Figure 3). The analysis of the MINERAL concepts is given in the following paragraphs.

INSERT FIGURES 2 and 3 ABOUT HERE

MINERAL Structuring Task

Given the words and phrases of the MINERAL concepts structuring task, (see Figure 1), the definition of a mineral provides one major structure. Mineral class membership and non-membership relations form a second structure. Both of these structures are shown in Figure 4. The hierarchical relations that exist between a specific kind of rock, the

minerals of which the rock is composed, and the minerals' chemical compositions, expressed using both a chemical name (e.g., calcium carbonate) and a chemical formula (e.g., $CaCO_3$), define a third structure (see Figure 5). Although this structure is designated "hierarchical," it should be noted that it is composed of two different relations. Limestone physically contains calcite crystals. Calcite "contains" calcium carbonate in the sense that, upon chemical analysis, the mineral calcite will be found to consist of calcium carbonate, which is presumed to mean molecules of calcium carbonate.

INSERT FIGURES 4 and 5 ABOUT HERE

The structure in Figure 6 is a representation reflecting the chemical relationships among the words, as contrasted with the geological relationships represented in Figure 5. Note particularly that from a chemical perspective, calcite, limestone, and sea shells are roughly analogous, while geologically they are quite distinct. Figure 7 depicts graphically how the chemical properties of several substances are compared with the properties that define the characteristics of minerals to determine whether or not the substance in question is a mineral.

INSERT FIGURES 6 and 7 ABOUT HERE

The integration of the six structures shown in Figures 4 through 7 into one standard structure is somewhat easier to perform "in the head" than on paper. As we have done it (Figure 8), many of the subtleties of the six separate structures are no longer evident. Nevertheless, this integrated structure does depict all the essential relationships shown in the separate structures and, therefore, can serve satisfactorily as the standard structure. By analyzing this standard structure, we can identify the crucial attributes exhibited in it and prepare a qualitative description of these. Using the descriptions of the attributes, we designate a series of structure classes for the MINERAL concepts structuring task. A summary of these MINERAL structuring classes is shown in the chart of Figure 9. This chart is similar in form to the one shown in Figure 3 for the ROCK structure classes, and the function which the two charts serve for us is the same.

INSERT FIGURES 8 and 9 ABOUT HERE

Identification of High- and Low-Structuring Groups

The main purpose of our analysis of knowledge structure representations is to establish a means by which "high" structuring students and "low" structuring students can be identified. Once a series of structure classes has been designated for a set of concepts, we can use the descriptions of the classes to decide which attributes student structures must display to classify them as high or low structurers. Since two series of structure classes were constructed,

one for the ROCK concepts (Figure 3) and another for the MINERAL concepts (Figure 9), corresponding high- and low-structuring groups were identified.

For the ROCK concepts structuring task, high structurers were those students whose structures displayed attributes equal to or greater than those of class W-5 on the ROCK structure classes (see Figure 3). The criterion for low structurers was a rating less than or equal to class W-3 on the post-instructional ROCK task and a rating of less than class W-3 on the pre-instructional ROCK task.

For the MINERAL concepts structuring task only a student whose MINERAL structure was rated as class W-5 or W-6 (see Figure 9) on the pre- or post-task was designated as a high structurer. A student who was rated as class W-3 or lower on both the pre- and post-task was designated as a low structurer.

Since we had little reason to expect that success at structuring concepts in our tasks would depend to a significant extent on content specific characteristics, we decided against splitting the sample into the subgroupings, high-high, high-low, low-high, and low-low.

Analyses of Scores and Items

The three parts of the written test we administered before and after instruction yielded scores for each student's performance on items testing for geology knowledge (part 1) and on two kinds of verbal problem items, analogies (part 2) and set-membership (part 3). We also obtained each student's I.Q. score, based on a recent administration of

the Otis-Lennon Mental Abilities Test. For every score, the usual descriptive statistics were calculated for the total group of students, as well as the product-moment correlations between every pair of scores. Using a t-test for correlated groups, we tested the significance of the difference between the means before and after instruction on each score. The same sequence of analyses was repeated four times: for students who were identified for the high-structuring group on the basis of the ROCK concepts structuring task, for students who were so identified for the low-structuring group, and for the high- and low structuring groups of students identified on the basis of the MINERAL concepts structuring task. Using a t-test for independent groups, we tested the significance of the difference between the means of the high- and low-structuring groups on each score.

Results

Pre- to Post-Instructional Changes in Scores

In this and the following two sections, we present the results of analyses of nine score variables, viz:

Geology Knowledge Items--consisting of items administered both before and after instruction to test the students' knowledge of the geology subject matter in the ITE Minerals and Rocks; maximum possible score: 45

Variable 1 - pre-instructional score

Variable 2 - post instructional score

Geology Knowledge Percent--percentage of correct responses on the geology knowledge pretest with a total of 45 points and on the

geology knowledge posttest with a total of 62 points; maximum possible score: 100

Variable 3 - Pre-instructional score

Variable 4 - Post-instructional score

Analogies Items--maximum possible score: 17

Variable 5 - Pre-instructional score

Variable 6 - Post-instructional score

Set-Membership Items--maximum possible score: 12

Variable 7 - Pre-instructional score

Variable 8 - Post -instructional score

I.Q.-- Variable 9

For each of the nine variables just described, the means and standard errors for all 30 students in the study are presented in Table 1. This table also shows the pre- to post-instructional changes in mean scores on Geology Knowledge Items, Geology Knowledge Percent, analogies items, and set-membership items. The statistical significance of each of these changes was tested using a t-test for correlated means, and the results of these tests also are shown in Table 1. We found that the pre- to post-instructional gains in means scores were statistically significant ($p<.01$) for Geology Knowledge Items, Geology Knowledge Percent, and analogies items, but there was not a significant gain at the .05 level for the set-membership items.

INSERT TABLE 1 ABOUT HERE

Comparisons of High- and Low-Structuring Groups

As described in the discussion of our methods of analysis, we identified 10 students in the high-structuring group and 12 students in the low-structuring group on the basis of the ROCK concepts structuring task. Prior to instruction, the more competent structurers recognized a far greater number of terms on both the ROCK and MINERAL concepts structuring tasks than did the less competent structurers. Frequency counts of unrecognized terms for both structuring groups on each task (prior to instruction as well as after instruction) appear in Table 2. Further examination of Table 2 shows that the pre-instructional difference between high- and low-structuring groups in unrecognized terms has largely disappeared by the end of instruction. The means and standard errors for all nine variables listed above for the two groups are presented in Table 3. This table also shows the results of the t-test used to test the statistical significance of pre- to post-instructional changes in mean scores.

INSERT TABLES 2 AND 3 ABOUT HERE

The statistical significance of the difference between the means on each variable for the high- and low-structuring groups was tested using a t-test for independent means. The results of these tests are presented in Table 4. Using these results and those shown in Table 3, we can compare the several scores obtained by the high- and low-structuring groups that we identified from the ROCK concepts

structuring task.

INSERT TABLE 4 ABOUT HERE

Before instruction the high-structuring group performed better than the low-structuring group (difference between means significant at the .05 level) in both the Geology Knowledge Items and Geology Knowledge Percent scores. For both scores the pre- to post-instructional gains in the means were statistically significant for both groups. However, the post-instructional differences between the means for both the Geology Knowledge Items and Percent Scores for the two groups are not statistically significant ($p>.1$) We observe a similar result for the analogies items score. Here the high-structuring group's pre-instructural mean is significantly higher ($p<.01$) than the mean of the low-structuring group. The latter group's pre- to post-test gain is statistically significant ($p<.01$) while the high-structuring group's gain is not, and the post-instructional difference between the means of the two groups on the analogies items is not statistically significant at the .05 level.

The high-structuring group also outperformed the low-structuring group on the set-membership items score before instruction (difference between means significant at the .05 level). Here, however, the pre- to post-instructional gain was statistically significant ($p<.05$) for the high-structuring group while the low-structuring group did not gain.

The post-instructional difference between the means of the two groups on the set-membership items is significant at the .01 level. Finally, the difference between the two groups' means on the I.Q. score is significant at the .05 level.

In addition to designating high- and low-structuring groups of students on the basis of the ROCK concepts structuring task, we also employed the student response structure from the MINERAL concepts structuring task to identify high and low groups. Using the criteria described in the discussion of our methods of analysis, we identified 9 students in the high-structuring group and 10 students in the low-structuring group on the basis of the MINERAL concepts structuring task. Of these 9 high-structuring group students, 5 also were members of the high-structuring group of ROCK concepts, and of the 10 low-structuring group students on MINERAL concepts, 7 also were in the low-structuring group on ROCK concepts. While the overlap in membership of the high- and low-structuring groups based on the two concepts structuring tasks is considerable, the performance of the high and low groups on MINERAL concepts was somewhat different from the high and low groups of ROCK concepts on the nine variables for which scores were obtained.

In Table 5 we present the means and standard errors for all nine variables and the significance tests for pre- to post-instructional changes in means scores of the high- and low-structuring groups on the basis of the MINERAL concepts structuring task. Table 6 shows the siginificance tests for the difference between the means on each variable for the high- and low-structuring groups.

INSERT TABLES 5 AND 6 ABOUT HERE

The first four lines of Table 6 show that the means of the high-structuring group for both the Geology Knowledge Items and Geology Knowledge Percent scores were higher than the means of the low-structuring group both before and after instruction, but neither difference is statistically significant ($p > .1$) on either occasion. Nevertheless, as Table 5 shows, both groups made statistically significant pre- to post-instructional gains in means scores for both Geology Knowledge Items and Geology Knowledge Percent. Both groups also made statistically significant gains in the means for the analogies items scores from before to after instruction. However, we see in Table 6 that the difference between the means of high- and low- structuring groups for the analogies items scores is not statistically significant at the .05 level either before or after instruction.

For the set-membership item scores, the difference between the means of the high- and low-structuring groups is statistically significant ($p < .01$) before instruction, as well as after instruction. The pre- to post-instructional gain in the mean score of the high-structuring group is significant at the .05 level, but there is no change in the mean score of the low-structuring group. Finally, comparing the mean I.Q. scores of the high- and low-structuring groups based on the MINERAL concepts structuring task, we see that their difference is not statistically significant ($p > .1$).

Summary of Score Comparisons

The three pre- to post-instructional gains in mean scores which are statistically significant for the total group (Table 1) also are statistically significant for each high- and low-structuring group (Tables 3 and 5), whether identified on the basis of the ROCK concepts or the MINERAL concepts structuring task. Thus, improvement from before to after instruction was made in the Geology Knowledge Items, Geology Knowledge Percent, and analogies items scores for both the high-structuring and low-structuring students. The findings are different, however, for the set-membership items score. Here, the pre- to post-instructional gains in mean scores are statistically significant for the high-structuring students, identified by either set of concepts, but no statistically significant improvement is shown by the low-structuring students.

We also have four mean scores that compare high- and low-structuring students' success in solving verbal problems. When the groups are identified on the basis of the MINERAL concepts structuring task, the high-structuring group performs significantly better than the low-structuring group in two of the four instances, viz., on the set-membership items before and after instruction (Table 6). We also note in Tables 4 and 6 that in those instances where the mean score of the high-structuring group on the analogies or set-membership items is not significantly different at the .05 level from the mean score of the low-structuring group, the observed difference does approach this level of statistical significance. The probability of obtaining a t-value as large as the one calculated is less than .10 in each of these instances.

All in all, the comparisons of mean scores provide some positive evidence that students identified as being in a high-structuring group are more successful in solving verbal problems than students in a low-structuring group.

Discussion

The results of this study suggest that students who are more competent structurers, as identified by applying the ConSAT, tend to be more successful than less competent structurers in solving problems in which they must induce structures. Students' performance on set-membership items, where the difference between the means for the more and less competent structurers was statistically significant at the .01 level, supplies the most clear evidence for this interpretation. The results for the analogies items also contribute to this interpretation. On analogies items, the more competent structurers in the ROCK concepts structuring tasks outperformed the less competent structurers prior to instruction ($p<.05$), and in the three remaining instances (post-instruction for the ROCK task groups, and pre- and post-instruction for the MINERAL task groups), the statistical tests of the differences between means on analogies approached the .05 significance level.

Two pieces of evidence suggest that, while the more competent structurers may have had more concepts committed to memory before instruction, this advantage has disappeared after instruction. Indicative of this pre-to-post trend are the observed frequencies of unrecognized terms (see Table 2), as well as the Geology Knowledge item

results, where no significant difference between the more competent and the less competent structurers was observed after instruction. Thus, after instruction the two groups appear to be working from essentially the same base set of concepts. If one pictures a concept network as a set of nodes and relationships between the nodes, a plausible interpretation of these results is that the memory of both groups of structurers contained very similar sets of nodes.

Instruction may have had an additional influence on students that helps to explain why the differences between the more competent and the less competent structurers are more evident on the set-membership items. We tentatively hypothesize that set-membership items are more difficult to process than analogies items since the solution of a set-membership item must be attained with fewer "clues". Since the instructional materials were designed to emphasize certain structural principles of geology explicitly, we believe it is reasonable to conjecture that instruction so designed offsets to some degree the advantage which the more competent structurers bring to the problem-solving task. Thus, on problems whose solutions call upon a greater ability to induce structures, the difference between the more and less competent structurers would become more apparent. These results tend to support Shavelson's (1973) contention that students who are better problem solvers following instruction form conceptual networks more readily than those who are poorer problem solvers. We feel, though, that our results tease out the relationship more clearly since in our case, the nature of the problem tasks was specified to a finer degree.

That the ConSAT differentiates students more on the basis of stable individual characteristics than on content specific attributes is indicated by our finding that only two students who were designated high on the basis of one grouping were low on the other. Five students were high on the basis of both the MINERAL and the ROCK concept structuring tasks, seven were low on both, and the remainder were a combination either of high and medium or of low and medium. Contributing to this interpretation is our observation, described in a previous report (Note 1), that less competent structurers on our geology concept structuring tasks were unable to structure thirty terms related to foods. None was able to generate a scheme of classification applicable to all the foods. They could only classify foods with which they or members of their immediate family had had experience, suggesting that they were unaware of structuring as a strategy for reducing large amounts of information into more manageable units.

Finally, as a procedure for probing knowledge structures, certain features of the ConSAT recommend its further development. The ability to probe for relations between concepts, to monitor and analyze structure changes of individuals as a result of instruction, and to probe for the integration of more than one kind of structure are the advantages we perceive.

References

Bhaskar, R., and Simon, H.A. Problem solving in semantically rich domains: An example from engineering thermodynamics, *Cognitive Science*, 1977, *1* (2), 193-215.

Bower, R.G. Cognitive psychology: an introduction. In W.K. Estes (Ed.), *Handbook of learning and cognitive process*. Vol. 1. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1975.

Champagne, A.B., and Klopfer, L.E. An individualized elementary school science program. *Theory Into Practice*, 1974, *13*, 136-148.

Champagne, A.B., and Klopfer, L.E. *Individualized science*. Kankakee, Illinois: Imperial International Learning Corporation, 1972-1975.

Eignor, D.R. *Statistical suggestions for the study of cognitive structures*. Paper presented at the annual meeting of the American Educational Research Association, Toronto, March, 1978.

Geeslin, W.E. and Shavelson, R.J. An exploratory analysis of mathematical structure in students' cognitive structure. *American Educational Research Journal*, 1975, *12* (1), 21-39.

Greeno, J.G. The structure of memory and the process of solving problems. In R.L. Solso (Ed.), *Contemporary issues in cognitive psychology*. Washington, D.C.: Winston, 1973.

Greeno, J.G. Process of understanding in problem solving. In N.J. Castellan, D. Pisoni, and G.R. Potts (Eds.), *Cognitive theory* Vol 2). Hillsdale, N.J.: Lawrence Erlbaum Associates, 1977.

Greeno, J.G. Natures of problem-solving abilities. In W.K. Estes (Ed.), Handbook of learning and cognitive processes. Volume 5. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1978.

Johnson, P.E., Curran, T.E., and Cox, D.L. A model for knowledge of concepts in science. Journal of Research in Science Teaching, 1971, 8 (1), 91-95.

Johnson, P.E. On the communication of concepts in science. Journal of Educational Psychology, 1969, 60, 32-40.

Kintsch, W. The representation of meaning in memory. New York: John Wiley & Sons, 1974.

McNemar, Q. Psychological Statistics. New York: John Wiley. 1962 (3rd edition).

Newell, A. and Simon, H.A. Human problem solving. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1972.

Preece, P.F.W. Mapping cognitive structure: A comparison of methods. Journal of Educational Psychology, 1976a, 68 (1), 1-8.

Preece, P.F.W. The concepts of electromagnetism: A study of the internal representation of external structures. Journal of Research in Science Teaching, 1976b, 13 (no. 6), 517-524.

Preece, P.F.W. A note on comparison of cognitive structure and subject-matter structure. Journal of research in Science Teaching, 1976c, 13 (no.4), 353-354.

Preece, P.F.W. Development trends in the continued word association of physics students. Journal of Research in Science Teaching, 1977, 14 (no. 3), 235-239.

Rumelhert, D.E. Notes on a schema for stories. In D.G. Bobrow and A.M. Collins (Eds.) Representation and understanding. New York: Academic Press, 1975.

Sacerdoti, E. A Structure for plans and behavior. The Artificial Intelligence Series. New York: Elsevier North-Holland, Inc., 1977.

Shavelson, R.J. Learning from physics instuction. Journal of Research in Science Teaching, 1973, 10 (2), 101-111.

Shavelson, R.J. Methods for examining representations of a subject-matter structure in a student's memory. Journal of Research in Science Teaching, 1974, 11 (3), 231-249.

Shavelson R.J. and Stanton G.C. Construct validation: methodology and application to three measures of cognitive structure. Journal of Educational Measurement, 1975, 12 (no. 2), 67-85.

Reference Notes

1. Champagne, A.B., Klopfer, L.E., DeSena, A.T., and Squires, D. Content structure in science instructional materials and cognitive structure in students' memories. Unpublished manuscript, 1977, Learning Research and Development Center, Pittsburgh (To be published in LRDC Publication series).

Table 1

Means and Standard Errors of All Variables for the Total Group and Pre- to Post-Instructional Changes[a]

	Variable	Mean	S.E.	PRE to POST Changes: Difference	S.E.	t
1	Geol PRE	22.30	0.80	+6.13	0.88	6.94**
2	Geol POST	28.43	1.08			
3	Geol % PRE	54.23	1.95	+9.50	1.78	5.32**
4	Geol % POST	63.73	2.29			
5	Analog PRE	7.13	0.47	+2.10	0.52	4.04**
6	Analog POST	9.23	0.54			
7	Set-M PRE	5.13	0.29	+0.60	0.31	1.92*
8	Set-M POST	5.73	0.40			
9	I.Q.	109.33	2.12			

[a] N = 30

* $p < .1$

** $p < .01$

Table 2

Unrecognized Words for Structuring Groups for Both Pre- and Post-Instructional Concept Structuring Tasks

	Pre-	Post-
Low		
Rock	42	2
Mineral	53	11
High		
Rock	10	0
Mineral	18	0

Table 3

Means and Standard Errors of All Variables for the High- and Low-Structuring Groups on the ROCK Concepts Structuring Task and Pre- to Post- Instructional Changes

	Variable	Mean	S.E.	PRE to POST Changes		
				Difference	S.E.	t
	High-Structuring Group on ROCK Concepts[a]					
1	Geol PRE	24.40	1.46	+5.30	1.61	3.30**
2	Geol POST	29.70	1.74			
3	Geol % PRE	59.20	3.57	+8.60	3.04	2.82*
4	Geol % POST	67.80	4.29			
5	Analog PRE	9.40	0.48	+1.00	0.70	1.43
6	Analog POST	10.40	0.81			
7	Set-M PRE	6.00	0.36	+1.40	0.58	2.41*
8	Set-M POST	7.40	0.72			
9	I.Q.	116.30	3.91			
	Low-Structuring Group on ROCK Concepts[b]					
1	Geol PRE	20.00	1.18	+6.00	1.35	4.45**
2	Geol POST	26.00	1.90			
3	Geol % PRE	48.75	2.88	+10.83	2.82	3.84**
4	Geol % POST	59.58	3.73			
5	Analog PRE	5.67	0.72	+2.58	0.83	3.11**
6	Analog POST	8.25	0.82			
7	Set-M PRE	4.42	0.48	−0.17	0.44	0.38
8	Set-M POST	4.25	0.35			
9	I.Q.	104.42	2.50			

[a] N = 10
[b] N = 12
* $p < .05$
** $p < .01$

Table 4

Significance of Difference Between Means on Each Variable for High- and Low-Structuring Groups on the ROCK Concepts Structuring Task

	Variable	Difference Between Means (High-Low)	S.E.	t
1	Geol PRE	4.40	1.86	2.37**
2	Geol POST	3.70	2.62	1.41
3	Geol % PRE	10.45	4.54	2.30**
4	Geol % POST	8.22	5.67	1.45
5	Analog PRE	3.73	0.90	4.13***
6	Analog POST	2.15	1.16	1.85*
7	Set-M PRE	1.58	0.63	2.52**
8	Set-M POST	3.15	0.75	4.16***
9	I.Q.	11.88	4.50	2.64**

* $p < .1$
** $p < .05$
*** $p < .01$

Table 5

Means and Standard Errors of All Variables for the High- and Low-Structuring Groups on the MINERALS Concepts Structuring Task and Pre- to Post-Instructional changes

	Variable	Mean	S.E.	PRE to POST Changes		
				Difference	S.E.	t
	High Structuring Group on MINERALS Concepts[a]					
1	Geol PRE	24.44	1.71	+5.89	1.13	5.20**
2	Geol POST	30.33	1.85			
3	Geol % PRE	59.44	4.12	+10.56	4.35	2.43*
4	Geol % POST	70.00	4.08			
5	Analog PRE	8.22	0.76	+2.78	0.71	3.93**
6	Analog POST	11.00	0.83			
7	Set-M PRE	5.89	0.45	+1.89	0.61	3.09*
8	Set-M POST	7.78	0.76			
9	I.Q.	117.44	4.08			
	Low-Structuring Group on MINERALS Concepts[b]					
1	Geol PRE	21.10	1.53	+6.50	1.72	3.78**
2	Geol POST	27.60	2.66			
3	Geol % PRE	51.40	3.72	+9.40	2.71	3.46**
4	Geol % POST	60.80	4.82			
5	Analog PRE	6.10	0.89	+2.40	0.78	3.09*
6	Analog POST	8.50	0.91			
7	Set-M PRE	4.20	0.33	0		
8	Set-M POST	4.20	0.51			
9	I.Q.	108.50	3.18			

[a] N = 9
[b] N = 10
* $p < .05$
** $p < .01$

Table 6

Significance of Difference Between Means on Each Variable for High- and Low-Structuring Groups on the MINERALS Concepts Structuring Task

	Variable	Difference Between Means (High-Low)	S.E.	t
1	Geol PRE	3.34	2.29	1.46
2	Geol POST	2.73	3.29	0.83
3	Geol % PRE	8.04	5.54	1.45
4	Geol % POST	9.20	6.39	1.44
5	Analog PRE	2.12	1.18	1.80*
6	Analog POST	2.50	1.24	2.01*
7	Set-M PRE	1.69	0.55	3.06**
8	Set-M POST	3.58	0.90	3.98**
9	I.Q.	8.94	5.14	1.74

* $p < .1$
** $p < .01$

Practice Task

body	heel
ears	metatarsus
eyes	nose
face	soul
foot	toes

ATOM Task

atoms
chemical compounds
chemical elements
chemical substances
molecules

ROCK Task

granite	metamorphic
igneous	pumice
lava	rock
limestone	sediment
magma	sedimentary
marble	shale
slate	

MINERAL Task

C	inorganic solid substances
$CaCO_3$	limestone
calcite	mineral
calcium carbonate	NaCl
carbon	shells of sea animals
diamond	substances with a characteristic crystalline structure
graphite	substances with a definite chemical composition
halite	naturally occurring substances
	table salt

Figure 1. Words used in the concept structuring tasks.

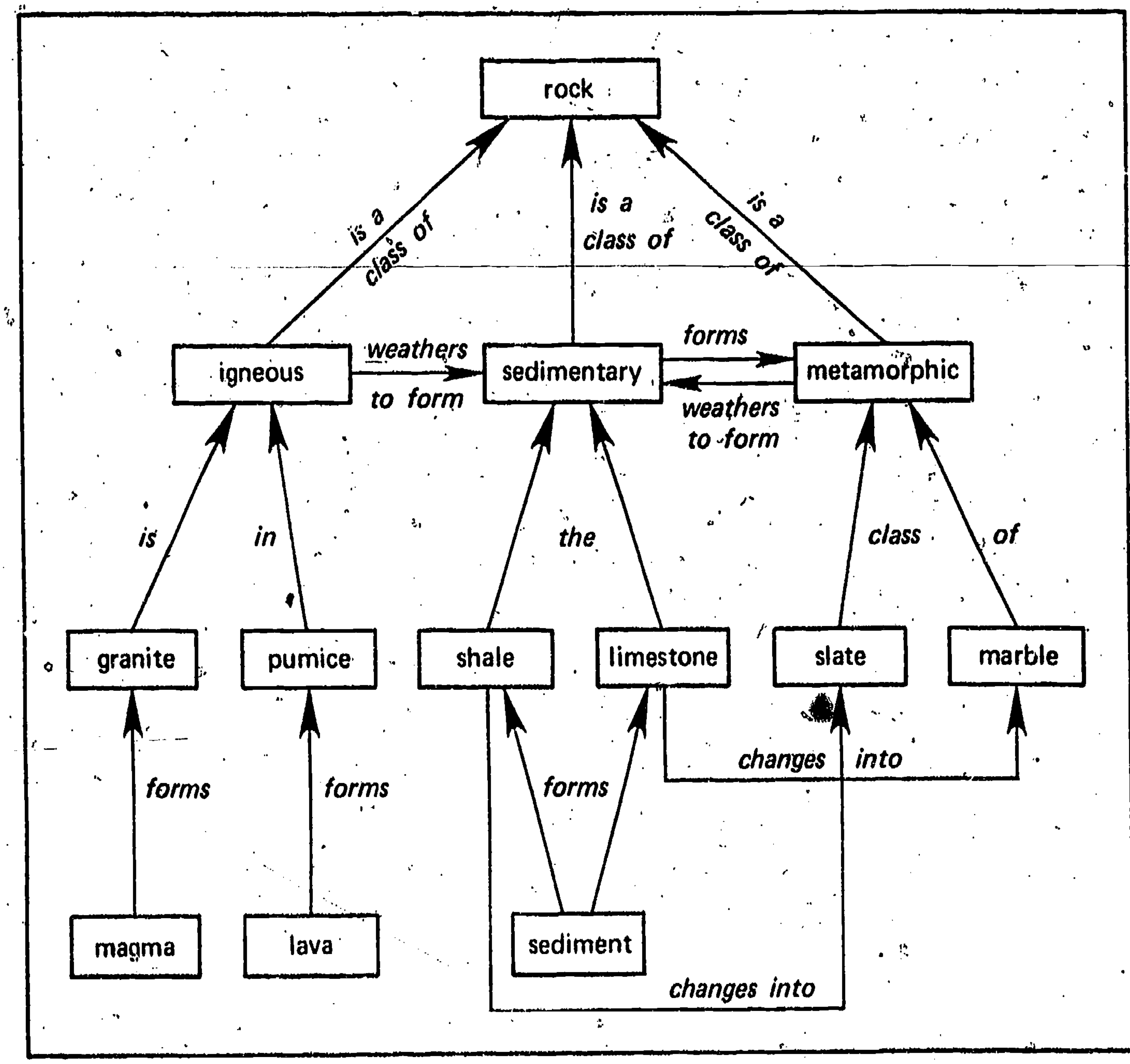
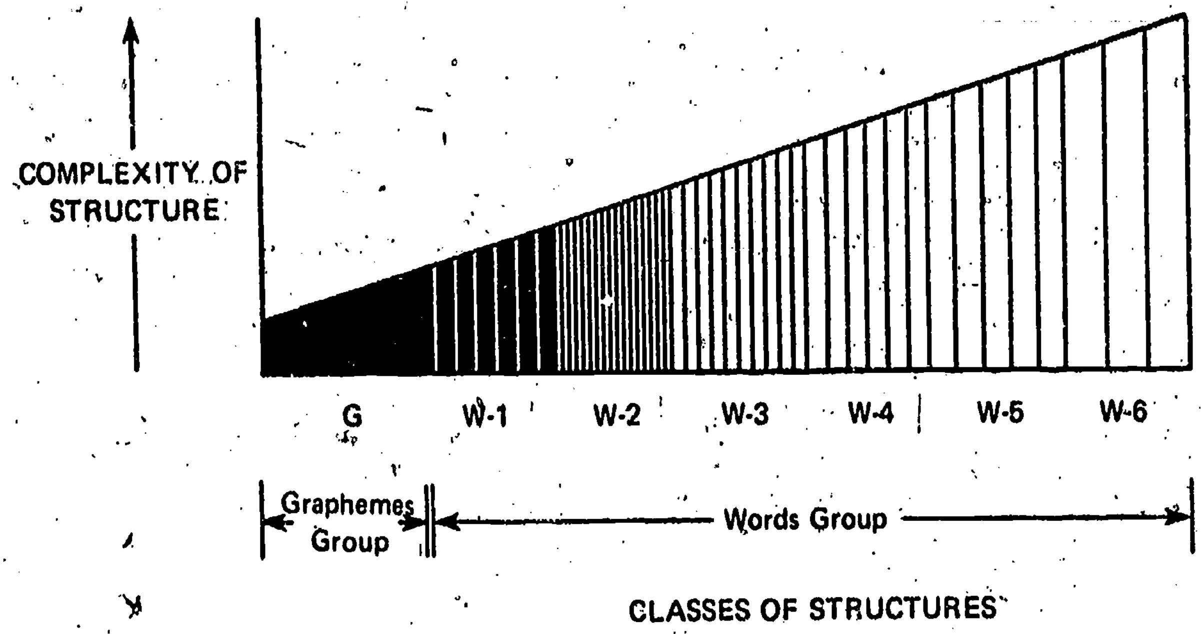


Figure 2. Integrated structure showing hierarchical and transformation relations of the thirteen words in the ROCK task.



CLASS	ATTRIBUTES OF THE CLASS
W-6	integration of hierarchical structure and transformational structure into a single structure
W-5	hierarchical structure plus fragment of transformational structure
W-4	hierarchical structure or transformational structure
W-3	fragments of the hierarchical and/or transformational structures
W-2	two or more words related by a single technical or general usage label
W-1	two or more words, unspecified relationships
G	two or more words related by a single morphological characteristic

Figure 3. Attributes and classes for ROCK structures.

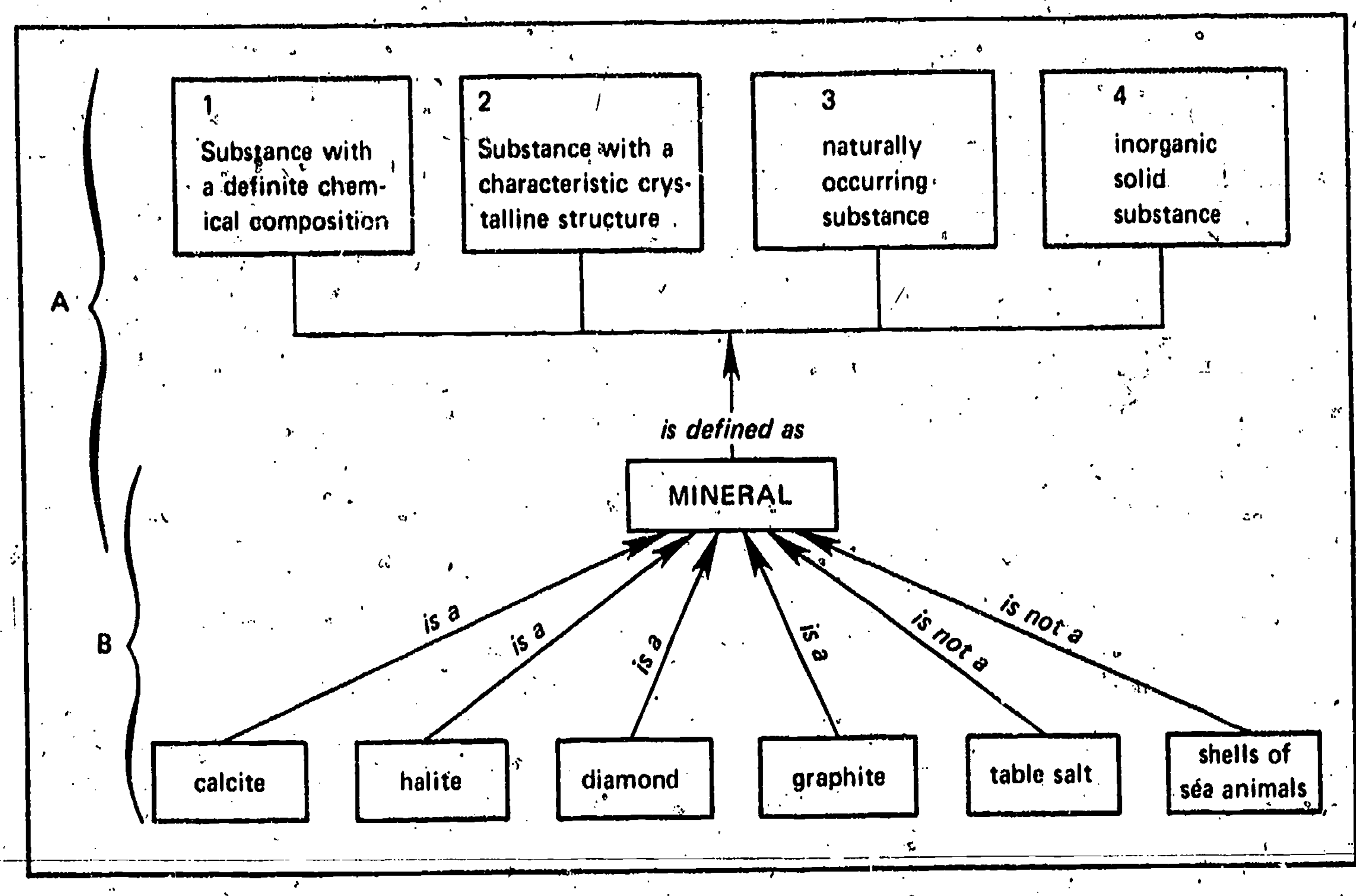


Figure 4. Mineral definition [A] and mineral class membership and non-membership [B] structures.

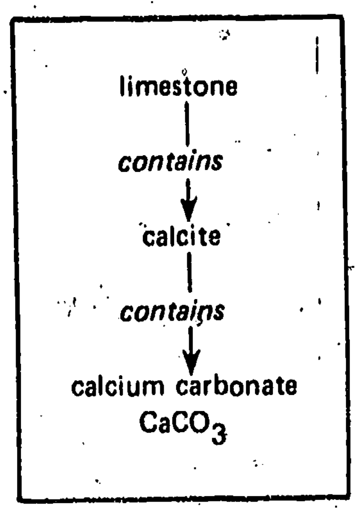


Figure 5. Rock composition structure.

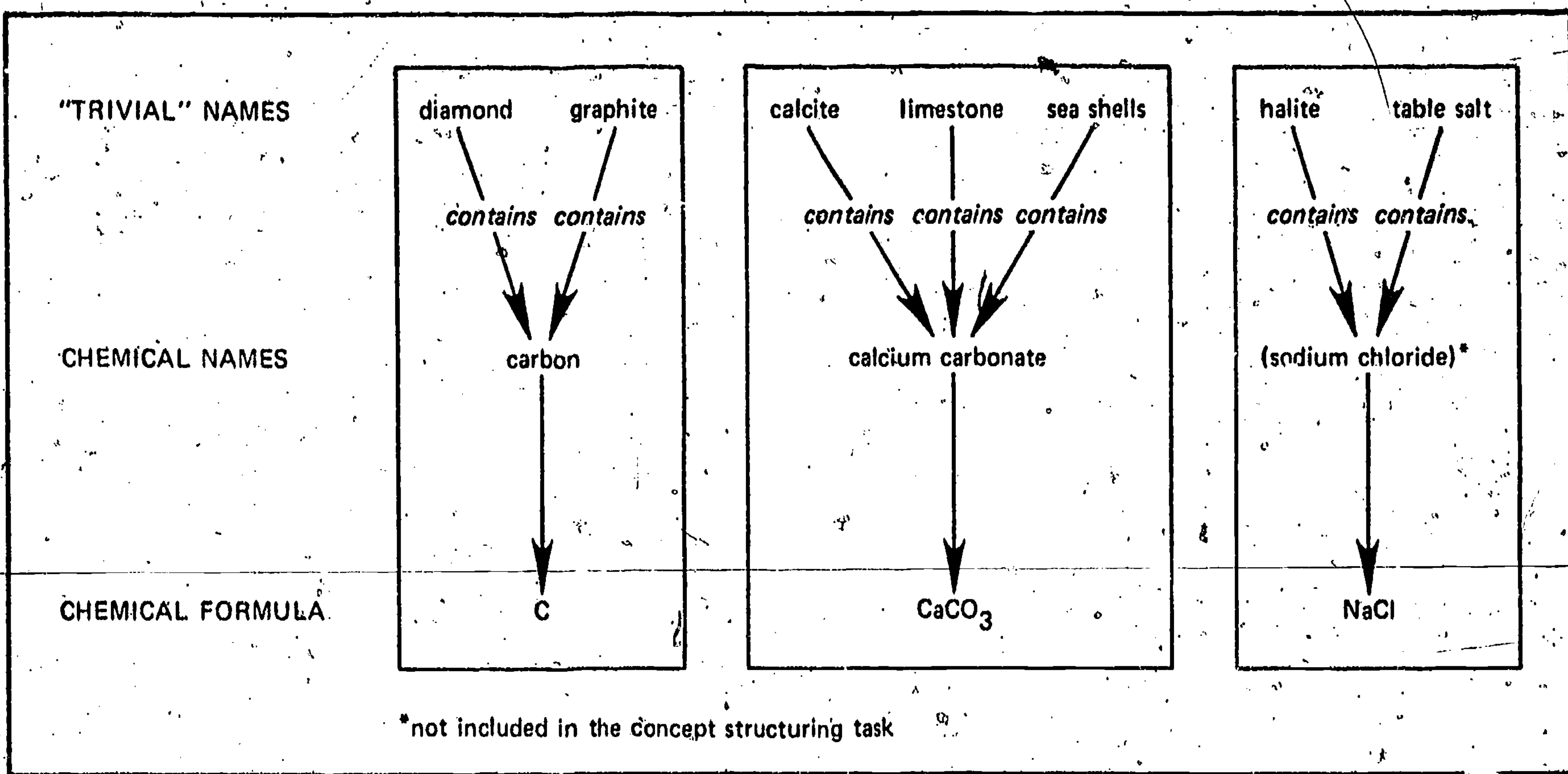


Figure 6. Chemical relations structure.

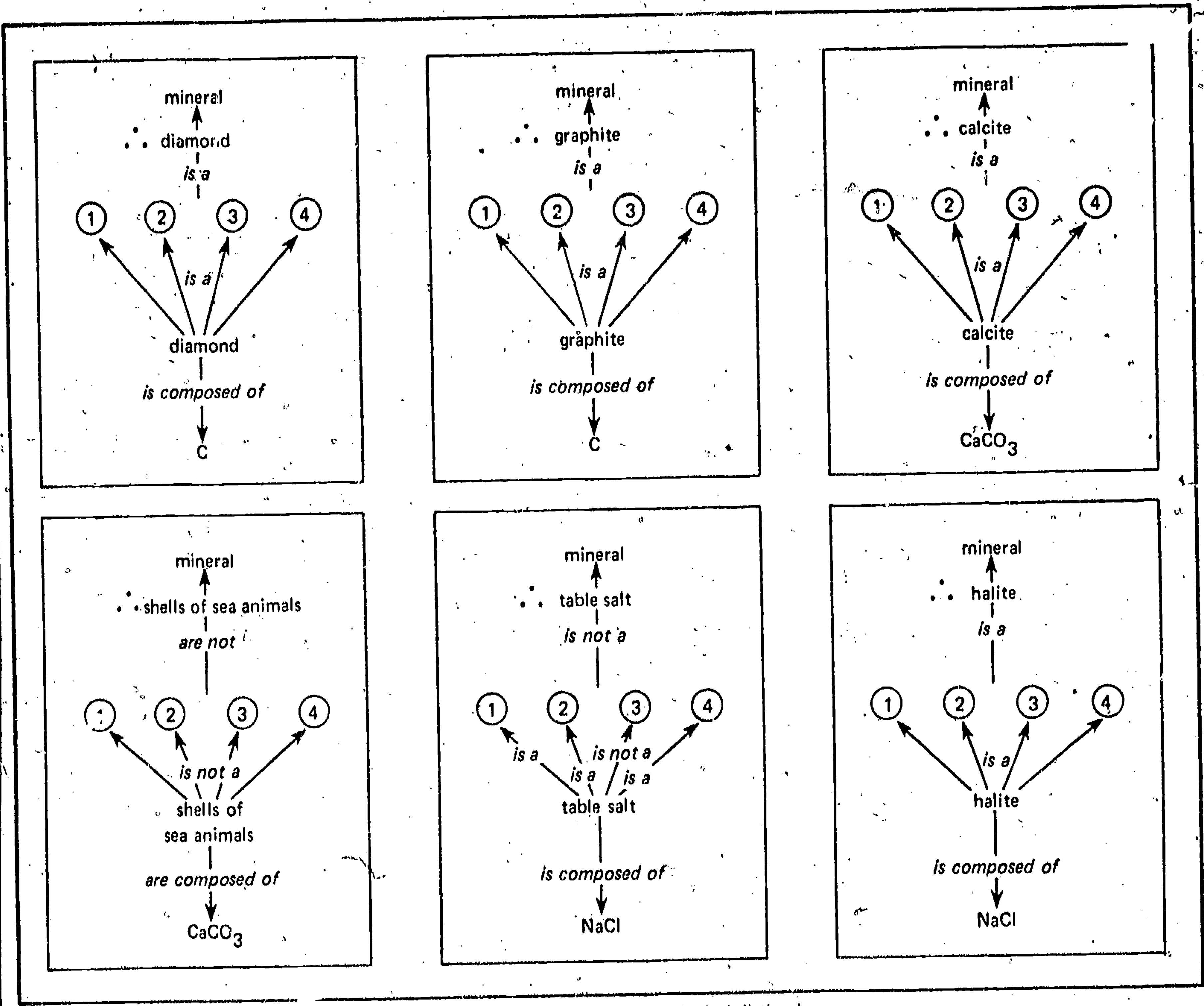


Figure 7. Origins of chemical and geological distinctions.

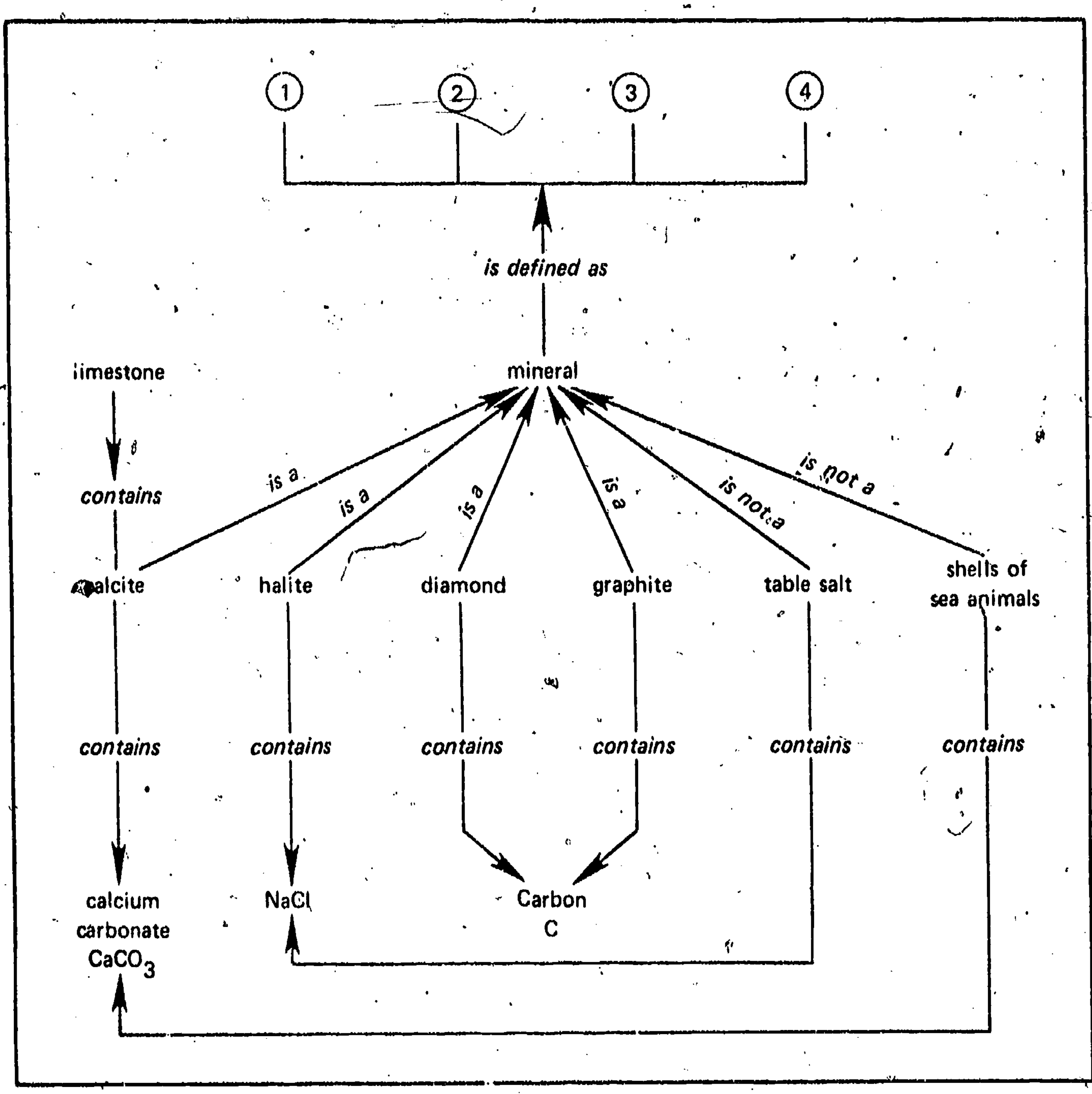
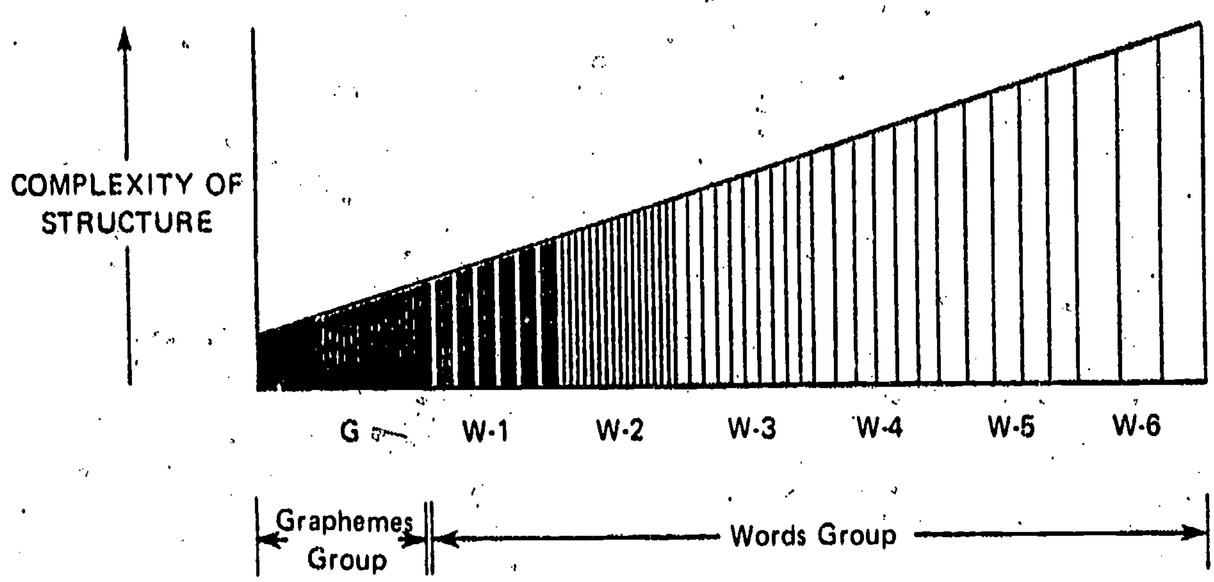


Figure 8. Integrated structure.



CLASS	ATTRIBUTES OF THE CLASS
W-6	integration of relationships among three or more terms integrated with characteristics of minerals
W-5	relationships among four terms, example, limestone (rock) ↔ calcite (mineral) ↔ calcium carbonate (chemical name) ↔ $CaCO_3$ (chemical formula)
W-4	relationships among three terms: diamond ↔ C ↔ crystalline structure
W-3	relationship between two terms: table salt ↔ NaCl
W-2	two or more words related by a single technical or general usage label, ex: group of minerals, group of non-minerals or group of characteristics of minerals
W-1	two or more words, unspecified relationships

G	two or more words related by a single morphological characteristic

Figure 9. Attributes and classes for MINERAL structures.